

A Four Year Study of Bacteriological Characteristics at Recreational Beaches, Manitoba, Canada



A FOUR YEAR STUDY OF BACTERIOLOGICAL
CHARACTERISTICS AT RECREATIONAL BEACHES,
MANITOBA, CANADA.

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Abstract

The bacteriological characteristics of thirty-five beaches were monitored in Manitoba during 1984, 1985, 1986 and 1987. Fourteen of these beaches were assessed each year; the others were monitored on one or more years during the study period. The principal objective of the study was to determine whether or not the bacteriological quality of the major Manitoba beaches were acceptable in relation to surface water quality objectives for primary recreational activities. Additional information was also acquired that resulted in a greater understanding of microbial populations in Manitoba surface water. Such information, useful in water management programs, included the generation of data on fecal streptococci, *Escherichia coli*, *Staphylococcus aureus* and *Pseudomonas aeruginosa*, and determination of bacterial species enumerated in the fecal coliform and fecal streptococci analyses.

The data were compared to the 60% and 90% confidence intervals for 30-day geometric mean and 1-day geometric mean fecal coliform objective of 200 organisms/100 mL. All beaches monitored did not exceed the 30-day objective during the study period with the exception of Matlock Beach, Lake Winnipeg, on one occasion during 1984. Other beaches were of acceptable quality in comparison to the recreational water quality objective during this averaging period. Most beaches located on Lake Winnipeg, however, exceeded at least the 60% confidence limit for the 1-day geometric mean fecal coliform objective on one occasion during each of the four years of the investigation. Extensive follow-up of such exceedences indicated that the events occurred at apparently random intervals and could not readily be associated with other possible contributing factors such as bather load, precipitation, wind direction or point-source contributions of fecal coliform bacteria. It was thought that the additional risk to bathers during these brief periods of time was not unacceptable.

Similar exceedences of the 1-day geometric mean fecal coliform objective were observed on Lake Dauphin beaches during 1986 but not during 1987. A single exceedence of the 1-day fecal coliform objective was observed at Red Rock Lake, located within Whiteshell Provincial Park, during the summer of 1987. All other beaches monitored in the central, western, southern and eastern regions of Manitoba did not exceed the fecal coliform objective.

The data generated during this extensive investigation adequately characterized the bacteriological quality of the beaches in the most heavily populated region of Manitoba. It is therefore not necessary to conduct further monitoring of this nature in the near future unless to address specific concerns or problems as evidenced by new medical information. Additional studies would also be warranted should alterations in major land-use practices occur near recreational areas or additional discharges of wastes of enteric origin be directed towards bathing areas.

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Introduction

Manitoba has exceptional opportunities for water-related recreation. Many of these opportunities are available within reasonable commuting distances from major urban centers and are utilized extensively by day campers. Most areas also have well developed camping facilities which enable extended recreational visits.

Water related recreational activities have been separated into two broad categories within Manitoba, based upon the probable extent of contact with the water. Primary recreation includes activities where immersion of the entire body, including the head, is probable. Examples include swimming, diving, wading and some shoreline activities, such as dabbling by young children (Williamson 1988a). The potential exists for the transmission of disease vectors via the water medium. Secondary recreation includes activities where the extent of contact with the water is only incidental to the activity (Williamson 1988a). Secondary recreation includes activities such as boating, canoeing, sailing and hiking. The potential for the transmission of disease is less likely with secondary recreational activities than with primary recreational activities.

The most common ailments associated with primary recreational activities in freshwater are firstly, infections of the skin, eyes, ears, nose and throat and secondly, gastroenteritis. A number of pathogenic bacteria have been implicated in bather-related infections of the skin, eyes, ears, nose and throat, including *Staphylococcus aureus* and *Pseudomonas aeruginosa*. The etiological agent responsible for bather-related gastroenteritis is thought to be a virus (Cabelli 1979). Symptoms of gastroenteritis amongst bathers are relatively benign and usually include fever, vomiting, diarrhea and stomach cramps (Cabelli 1979).

Scientists have been searching for the ideal indicator organism that could be practically measured in recreational waters and could be unequivocally linked to predictable rates of gastroenteritis amongst bathers. Intuitively, this link was expected to occur between some indicator of fecal contamination and bather-related disease incidence. The presence of fecal coliform bacteria in water is indicative of contamination by fecal material originating from the digestive tracts of warm-blooded animals. Thus, it is inferred that other more harmful pathogenic agents may also be present. Stevenson (1953) conducted one of the first epidemiological studies in this regard. Stevenson's investigation led to the present widely accepted fecal coliform criteria for the protection of primary recreational activities in water of 200 fecal coliforms/100 mL. This criteria was adopted in the United States (U.S. EPA 1976) and subsequently in jurisdictions in Canada (Alberta Environment 1977), including Manitoba (Clean Environment Commission 1977) and later in other Canadian jurisdictions (Health and Welfare Canada 1983, CCREM 1987).

Stevenson's (1953) study however, has been severely criticized for technical deficiencies. Other researchers have attempted to overcome these flaws and have similarly been criticized.

Cabelli (1981) conducted epidemiological studies of bather-related gastroenteritis amongst bathers at marine beaches in the United States and in Egypt. Dufour (1983) conducted similar studies at freshwater beaches in the United States. These researchers found relationships between both the definitive fecal coliform *Escherichia coli* and enterococci and bather-related gastroenteritis. The United States Environmental Protection Agency (1986) utilized the information generated from these studies to adopt new recreational water quality criteria within the United States. The resultant criteria for the protection of freshwater recreational beaches were 33

enterococci/100 mL and 126 *Escherichia coli*/100 mL. Noteworthy is the fact that a relationship between fecal coliform organisms and gastroenteritis was not detected. The mathematical equations derived from these studies indicated that at an *E. coli* density of 200 organisms/100 mL, approximately 9.9 persons out of every 1000 bathers could be expected to contract gastroenteritis.

Studies have similarly been conducted within Canada that utilized a somewhat different epidemiological design (Seyfried and Brown 1985). The results of these studies differ slightly from those of Cabelli (1981) and Dufour (1983). Seyfried (1987) observed a relationship between bather-related gastroenteritis and fecal coliform organisms but not with enterococci. Further, Seyfried (1987) determined that a recreational water quality objective of 100 fecal coliform organisms/100 mL was more effective in preventing bathing related disease than the objective of 200 fecal coliform organisms/100 mL. The mathematical equation derived from these latter studies indicated that at a fecal coliform density of 200 organisms/100 mL, approximately 19 persons out of every 1000 bathers could be expected to contract gastroenteritis. It is not known what risk is precisely associated with bathing in water containing a fecal coliform density of 200 organisms/100 mL.

Williamson (1985, 1988b) examined this information and made recommendations specifically for Manitoba's context. Williamson (1988b) recommended retention of the original fecal coliform criteria of 200 organisms/100 mL and the addition of an objective for *E. coli* of 200 organisms/100 mL. It was determined that the objectives for both fecal coliform and *E. coli* of 200 organisms/100 mL would provide equivalent protection. Within Manitoba, data indicated that *E. coli* comprised approximately 99% of the organisms enumerated within the fecal coliform analyses (Williamson 1988c). Williamson (1988b) further recommended that, due to the the lack of consensus with

regard to the utility of enterococci for use as a primary recreational water quality objective, an objective would not be recommended for adoption. However, it was recommended that enterococci analyses be included in future recreational water quality monitoring activities and that the field results be tentatively compared with a value of 50 enterococci/100 mL. This tentative objective was developed from the mathematical equations of Dufour (1983) and represents a similar risk as the objective for fecal coliform organisms of contracting gastroenteritis while bathing.

It is important to note that the recommendations of Williamson (1988b) follow closely those of Health and Welfare Canada (1983). However, Health and Welfare Canada (1983) recommended a single fecal coliform guideline based upon an average of samples collected over a 30-day period (a 30-day geometric mean). Williamson (1988b) has recommended procedures that should be used for shorter averaging periods as well as an objective for *E. coli* and a tentative objective for enterococci.

Major recreational beaches in Manitoba were monitored for bacteriological parameters during the summers of 1984, 1985, 1986 and 1987 in a joint study conducted by the Manitoba Department of Health and the Manitoba Department of Environment and Workplace Safety and Health. Although the data collected during 1984 and 1985 has been previously discussed (Williamson 1985; Sekla *et al.* 1987), it will be re-assessed within this report in relation to the data collected during 1986 and 1987.

Noteworthy is the fact that fecal streptococci were measured rather than enterococci. Enterococci are a sub-group of fecal streptococci and are comprised of *Streptococcus fecalis* and *S. faecium*. In addition to these species, fecal streptococci includes *S. avium*, *S. bovis*, and *S. equinus*. *Streptococcus durans* is considered by some to belong to the enterococci group, however, most researchers place

this species with the fecal streptococci. Because of the additional uncertainty of interpreting these results in comparison to the tentative objective for enterococci, these results were listed in the data supplement (Williamson 1988c) but will not be discussed in detail.

Field Methodology

The sampling locations are identified in Figure 1. Samples for bacteriological analyses were collected from three to five equidistant locations from each beach at temporal intervals ranging from once per month to eight times per month. The intensity of sampling depended upon the variability of the bacteriological parameters as well as the extent of recreational use. The sampling schedule was alternated in order that each beach could be sampled at different times during the day and on different days of the week over the duration of the summer. Consequently, most beaches were sampled occasionally on weekends. All samples were collected from approximately 1.0 m of water, and were collected between 0.1 and 0.3 m below the water surface. The pre-sterilized 125 mL glass sample containers were carefully filled in order to avoid contamination from the body of the sampler or from bottom sediments disturbed by the sampler.

The Lake Winnipeg and Whiteshell Provincial Park samples were collected, chilled and delivered to the Cadham Provincial Laboratory for initiation of analyses during the same day. Samples collected from central, western and southern areas of the Province were delivered to the Cadham Provincial Laboratory within 24 hours of collection.

A number of field observations were recorded during the sample collection

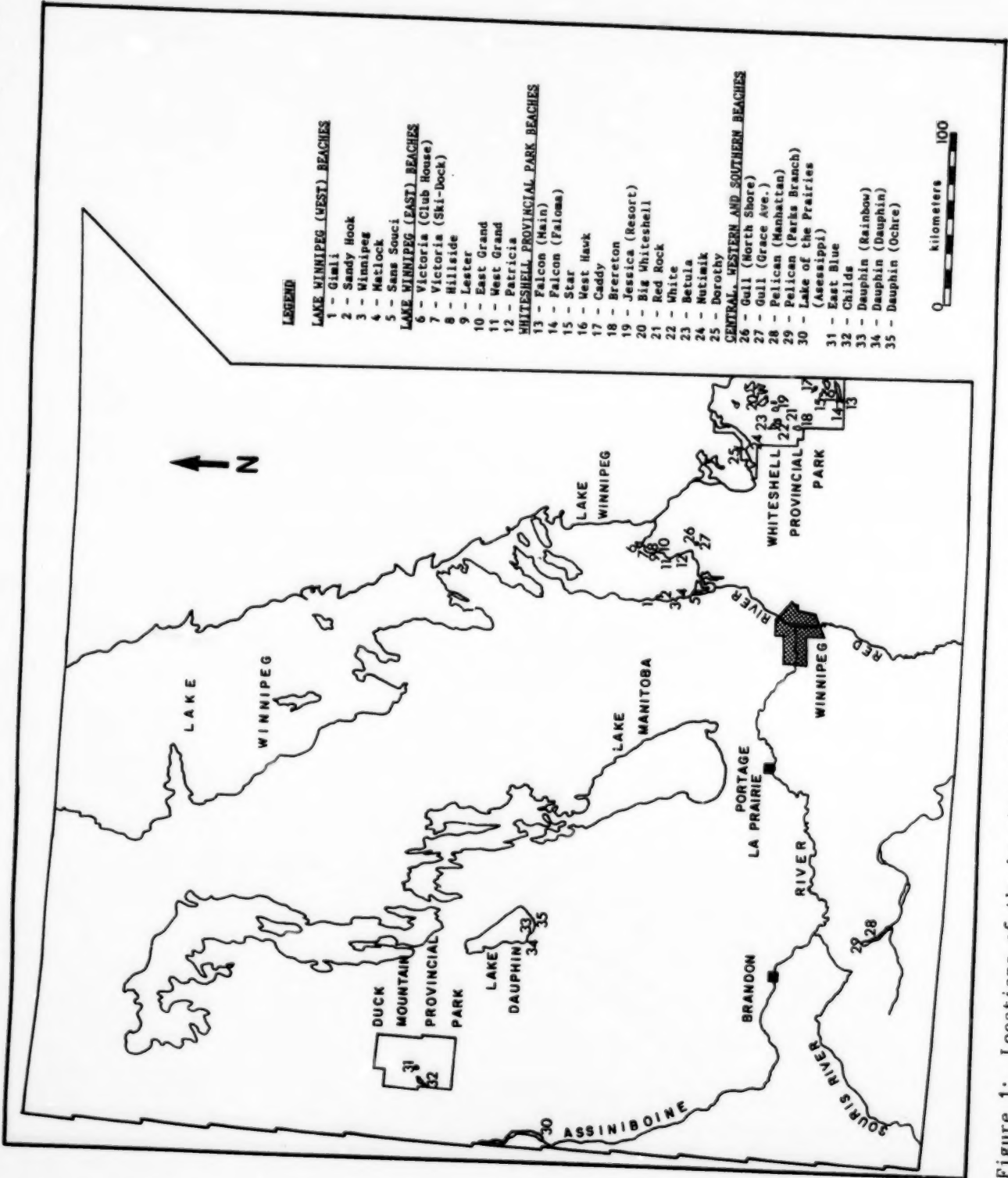


Figure 1: Locations of the beaches monitored during the study period.

procedure. These included air and water temperature, wind direction, cloud cover, recent precipitation, visible algae, wave action, turbidity, bather load and relative water colour.

Laboratory Methodology

Laboratory analyses for fecal coliform organisms followed the membrane filtration procedure outlined in Greenberg *et al.* (1980). Fecal streptococci were quantified using modified Greenberg *et al.* (1980) methods. The modification included the use of mEnterococcus agar (Difco) and the use of Levin *et al.* (1975) mE procedure. All fecal streptococci colonies were counted. *Escherichia coli* were analyzed using the method of Dufour *et al.* (1981). Colonies isolated by membrane filtration technique were then subjected to an in-situ urease test. All yellow/green colonies were counted. Confirmational analyses were conducted on 5% of the urease negative colonies using biochemical analyses (Christensen's urea, oxidase, Simmons citrate and indole production tests).

During the summer of 1987, randomly selected colonies enumerated in the fecal coliform and fecal streptococcus analyses were subjected to further speciation assessments (Buchanan and Gibbons 1975, 1980; Greenberg *et al.* 1985; Lennette *et al.* 1980; Pagel and Hardy 1980). Confirmation of fecal streptococcus strains were conducted on an automated Vitek System, manufactured by MacDonald Douglas Health Systems Co., Hazelwood, Missouri. Colonies were selected from beaches located on both the east and west sides of Lake Winnipeg and from the Red River near Selkirk.

Confidence Intervals

Monitoring recreational water quality for microbiological indicator organisms is essentially an exercise designed to make some inferences from the small volume of sample actually analyzed to the average conditions that existed throughout the entire bathing area. Sampling is conducted in such a manner to ensure the collection of representative samples during a period of time or times during which bathing occurs and using good collection techniques and analytical procedures. Nevertheless, numerous uncertainties exist. These are caused by imprecision within the analytical procedure, random errors associated with the collection techniques and the spatial and temporal heterogeneity of actual indicator organism distribution within the bathing area. Thus, the numerical results recorded within collected samples are only estimates of the actual indicator organism densities that existed throughout the bathing area. These combined uncertainties lead to a large degree of data variability.

Because of this variability, one cannot merely compare the average of a small number of samples to a recreational water quality objective and determine with absolute certainty that the objective was either exceeded or not. Rather, one can only ascribe a certain probability to this occurrence, given the results from the samples and the associated variability of the data. These concepts have been described in statistical theory (Mendenhall 1975; Youmens 1973).

Consequently, the data generated during this investigation was interpreted in terms of the degree of uncertainty or confidence that can be associated with exceedences of the recreational water quality objective. Two general types of data were generated within this investigation that lend themselves to comparison to the

recreational water quality objective. These are the results of the average of all samples collected from a given beach on one sampling occasion (1-day geometric mean) and the average of all samples collected during the previous 30-days (30-day geometric mean). Both types of data are useful. For example, the more sample results that are available, the greater confidence one can place on estimates of the actual average conditions that existed at that beach. This is illustrated in Figure 2. Figure 2 indicates that as the number of samples increase, the confidence intervals become closer to the fecal coliform objective of 200 organisms/100 mL. Note that with very few samples (e.g. 2 to 4 samples), little confidence can be placed in the results. However, as the number of samples approach 30 to 40, greater confidence can be associated with determining the probability of exceedences. Hence, using the 30-day geometric mean results, it can be determined with a certain degree of confidence whether the indicator organism densities at that beach exceeded the objective level during that 30-day period. This is useful for determining whether regulatory action, such as beach closure, is required. However, it does not ascertain the health risk to individual bathers who are likely not exposed to "average" conditions throughout a 30-day period, but rather are exposed to conditions that existed at the actual time of bathing. Consequently, the average indicator organism density within each individual day is also important.

These concepts are further illustrated in Figures 3 through 6. The 1-day geometric mean fecal coliform densities/100 mL from Matlock beach during 1986 are plotted in Figure 3. Note that the 1-day geometric mean is calculated from the 5 individual samples collected at equidistant intervals along the beach on each sampling occasion. The 60% and 90% confidence intervals were calculated using standard statistical procedures discussed by Williamson (1988b). The data indicated that on one occasion, the fecal coliform recreational water quality objective was exceeded.

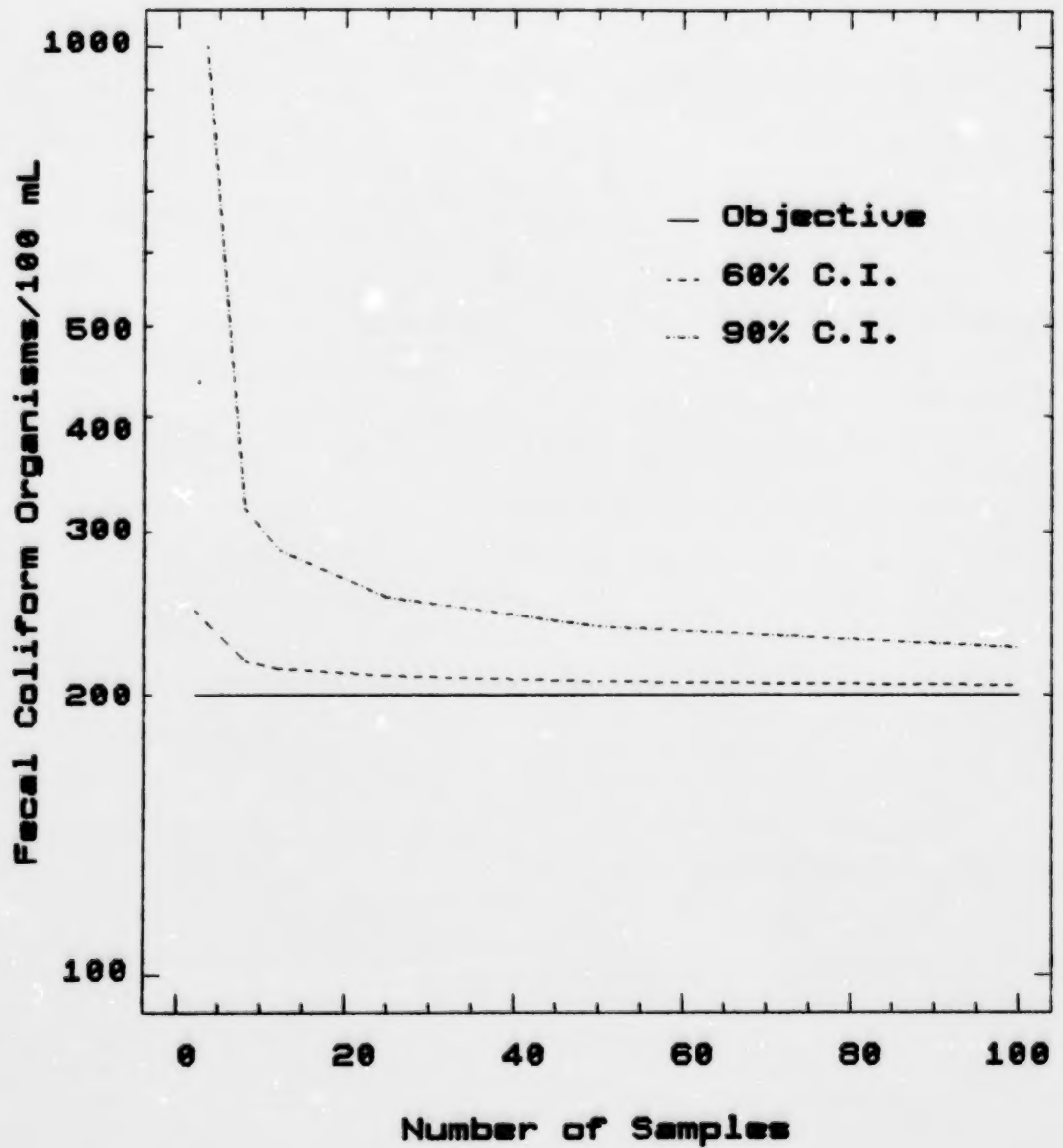


Figure 2: Relationship between the number of samples and the confidence that can be placed in determining the occurrence of exceedences.

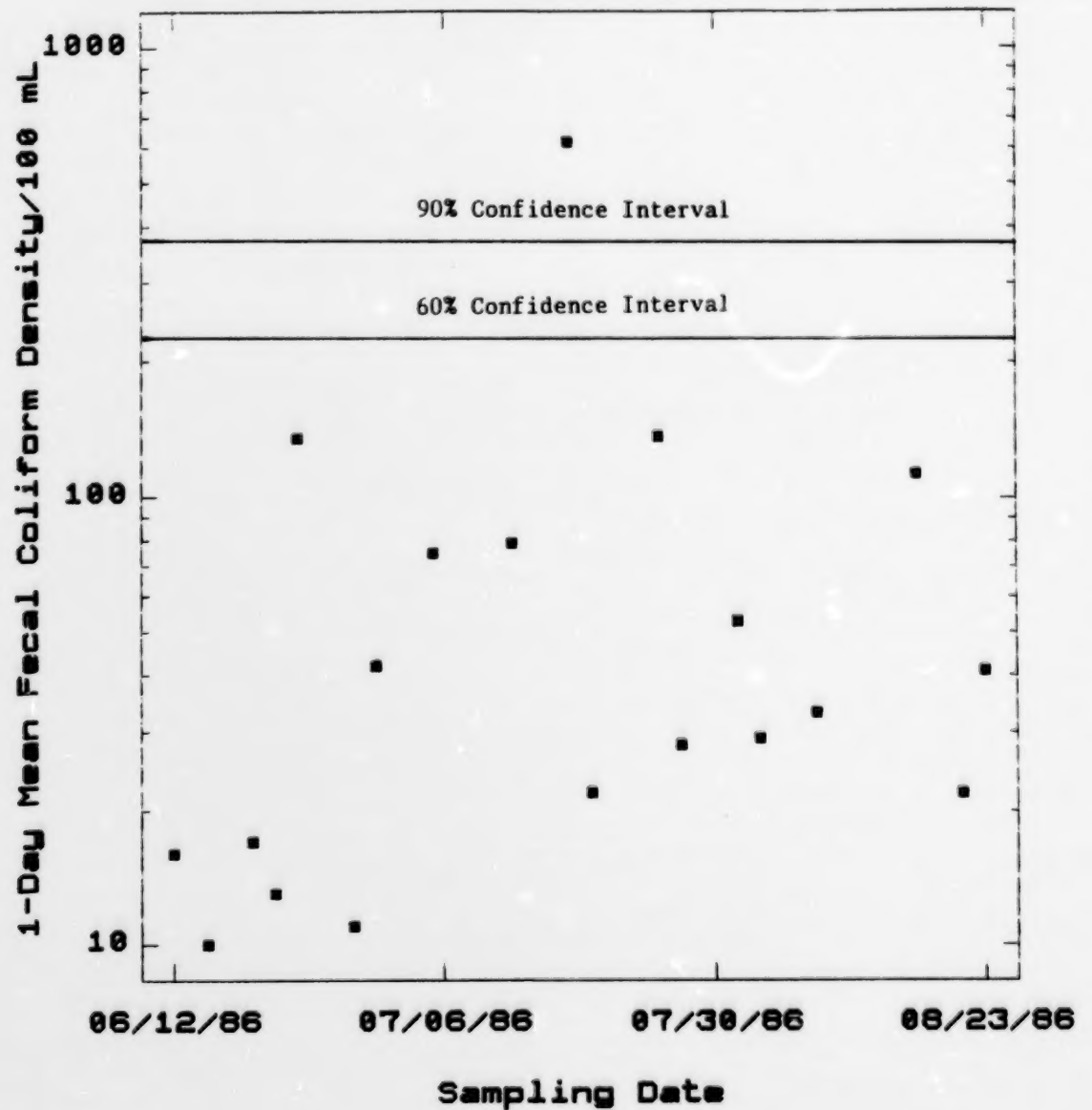


Figure 3: One-day geometric mean fecal coliform data at Matlock Beach, Lake Winnipeg, 1986, in comparison to the 60% and 90% confidence intervals above the recreational water quality objective.

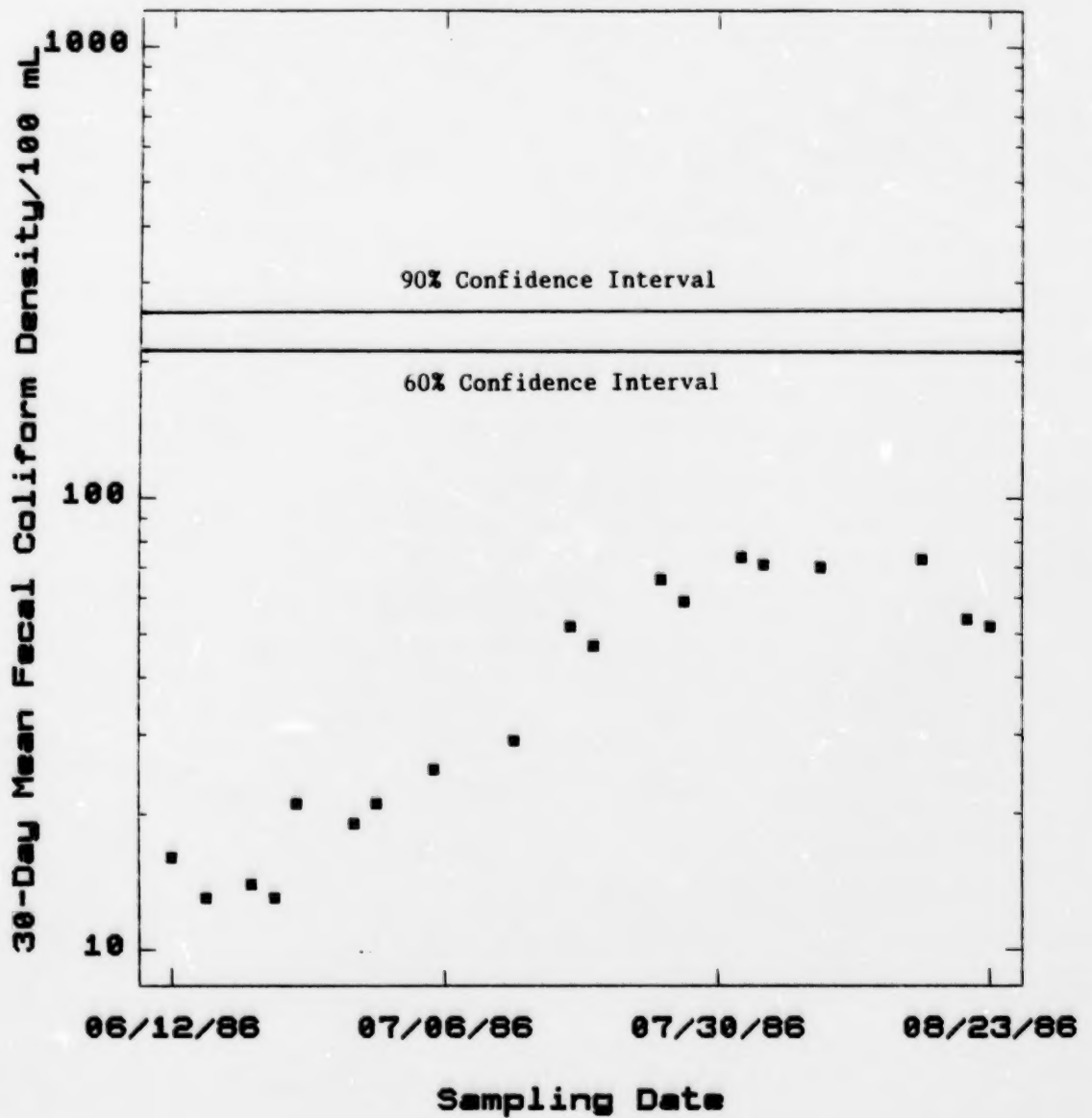


Figure 4: Thirty-day geometric mean fecal coliform data at Matlock Beach, Lake Winnipeg, 1986, in comparison to the 60% and 90% confidence intervals above the recreational water quality objective.

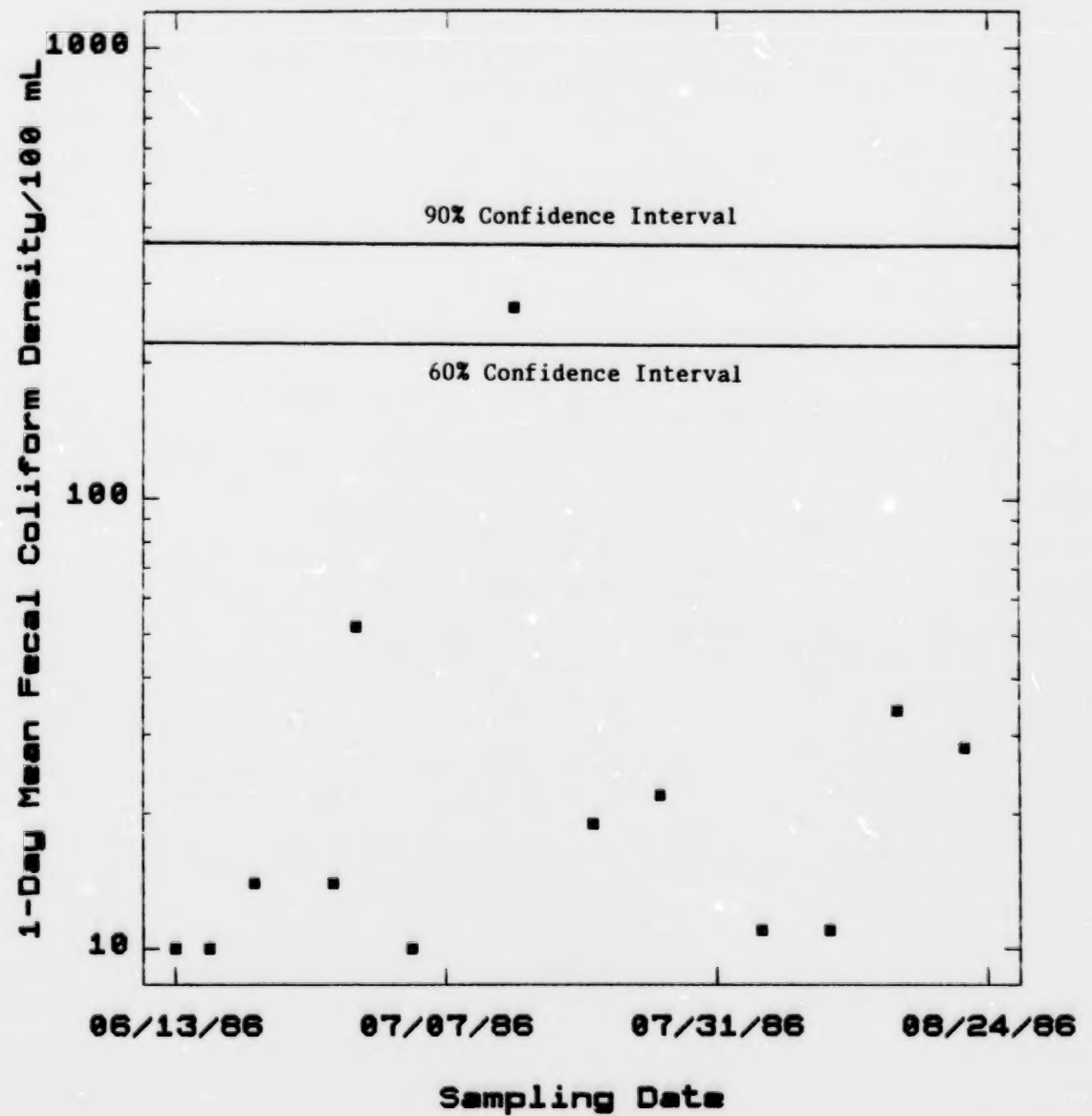


Figure 5: One-day geometric mean fecal coliform data at West Grand Beach, Lake Winnipeg, 1986, in comparison to the 60% and 90% confidence intervals above the recreational water quality objective.

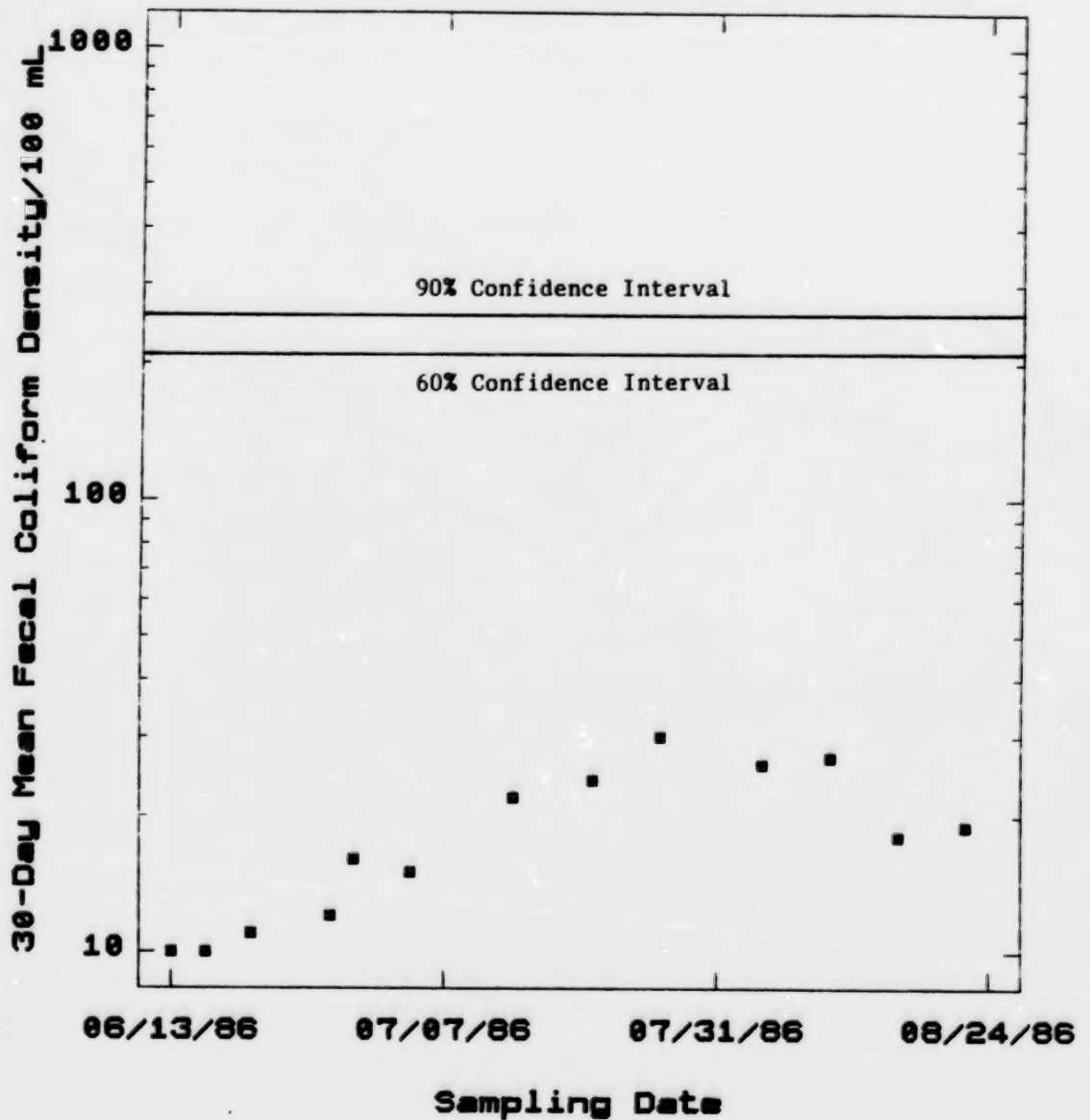


Figure 6: Thirty-day geometric mean fecal coliform data at West Grand Beach, Lake Winnipeg, 1986, in comparison to the 60% and 90% confidence intervals above the recreational water quality objective.

Further, one can associate a degree of confidence with this statement. That is, one can be 90% confident (*i.e.* correct 9 times out of 10) in concluding that the objective was actually exceeded on this occasion. However, when the 30-day mean fecal coliform density is plotted for this same beach and time period (Figure 4), the interpretation is somewhat different. This longer-term averaging period indicates that the fecal coliform recreational water quality objective was not exceeded. Hence, while the fecal coliform objective was exceeded on one sampling occasion during the summer of 1986, the objective was not exceeded during other individual sampling periods nor was it exceeded during the longer-term bathing period.

A further example is illustrated for Grand Beach (West) during 1986. The 1-day mean fecal coliform densities are plotted in Figure 5 along with the 60% and 90% confidence limits. These data indicated that the objective was exceeded on one occasion and that this can be stated with 60% confidence (*i.e.* correct 6 times out of 10). A greater degree of certainty cannot be ascribed to this occurrence since the 90% confidence interval was not exceeded. The 30-day mean fecal coliform data plotted in Figure 6 indicate that the objective was not exceeded during this longer averaging period. Hence, while an exceedence of the recreational water quality objective was observed, it occurred for only a brief period of time.

Results and Discussion

Lake Winnipeg Beaches

Beaches located at the communities of Gimli, Sandy Hook, Winnipeg Beach, Matlock and Sans Souci were monitored during the summers of 1984, 1985, 1986, and 1987. A summary of the number of exceedences of the recreational water quality objective is located in Table 1. All detailed data related to this study are located in the data

Table 1: Exceedences of the recreational water quality objective confidence intervals (CI) for fecal coliform organisms at Manitoba beaches. The number of samples is indicated by the entries, for example (n=24; 5). This indicates that each beach in that specific group was sampled 24 times with 5 samples being collected from each beach on each sampling occasion.

	1984				1985				1986				1987						
	1-DAY MEAN		30-DAY MEAN		1-DAY MEAN		30-DAY MEAN		1-DAY MEAN		30-DAY MEAN		1-DAY MEAN		30-DAY MEAN				
	60%CI	90%CI	60%CI	90%CI	60%CI	90%CI	60%CI	90%CI	60%CI	90%CI	60%CI	90%CI	60%CI	90%CI	60%CI	90%CI			
LAKE WINNIPEG (WEST)																			
Gimli	1	0	0	0		3	2	0	0		1	1	0	0		1	1	0	0
Sandy Hook	1	0	0	0		1	1	0	0		0	0	0	0		0	0	0	0
Winnipeg	1	0	0	0		1	0	0	0		1	0	0	0		1	0	0	0
Matlock	5	2	1	0		5	3	0	0		1	1	0	0		1	0	0	0
Sana Souci	2	0	0	0		3	1	0	0		0	0	0	0		0	0	0	0
	(n=24; 5)				(n=25; 5)				(n=19; 5)				(n=12; 5)						
LAKE WINNIPEG (EAST)																			
Victoria (Club House)	1	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
Victoria (Ski-Dock)	1	0	0	0		-	-	-	-		-	-	-	-		-	-	-	-
Hillside	0	0	0	0		-	-	-	-		0	0	0	0		0	0	0	0
Lester	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
East Grand	1	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
West Grand	2	0	0	0		1	1	0	0		1	1	0	0		1	1	0	0
Patricia	2	1	0	0		1	1	0	0		2	1	0	0		0	0	0	0
	(n=25; 5)				(n=13; 5)				(n=13; 5)				(n=12; 5)						
WHITESHELL PROV. PARK																			
Falcon (Main)	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
Falcon (Paloma)	0	0	0	0		-	-	-	-		-	-	-	-		-	-	-	-
Star	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
West Hawk	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
Caddy	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
Brereton	-	-	-	-		0	0	0	0		0	0	0	0		0	0	0	0
Jessica (Resort)	-	-	-	-		0	0	0	0		0	0	0	0		0	0	0	0
Big Whiteshell	-	-	-	-		0	0	0	0		-	-	-	-		-	-	-	-
Red Rock	-	-	-	-		0	0	0	0		0	0	0	0		0	0	0	0
White	-	-	-	-		-	-	-	-		0	0	0	0		1	0	0	0
Betula	0	0	0	0		-	-	-	-		0	0	0	0		0	0	0	0
Nutimik	0	0	0	0		0	0	0	0		0	0	0	0		0	0	0	0
Dorothy	0	0	0	0		-	-	-	-		-	-	-	-		0	0	0	0
	(n=24; 5)				(n=12; 3)				(n=8; 3)				(n=6; 3)						
CENTRAL, WEST, & SOUTH																			
Gull (North Shore)	-	-	-	-		0	0	0	0		-	-	-	-		-	-	-	-
Gull (Grace Ave.)	-	-	-	-		0	0	0	0		-	-	-	-		-	-	-	-
	(n=13; 3)				(n=13; 3)				(n=3; 5)				(n=2; 5)						
Pelican (Manhattan)	-	-	-	-		0	0	-	-		0	0	-	-		0	0	-	-
Pelican (Parks Branch)	-	-	-	-		0	0	-	-		0	0	-	-		0	0	-	-
Lake of the Prairies (Assessippi)	-	-	-	-		0	0	-	-		0	0	-	-		0	0	-	-
East Blue	-	-	-	-		0	0	-	-		0	0	-	-		-	-	-	-
Childs	-	-	-	-		0	0	-	-		0	0	-	-		-	-	-	-
	(n=24; 5)				(n=3; 5)				(n=3; 5)				(n=2; 5)						
Dauphin (Rainbow)	-	-	-	-		0	0	-	-		2	0	-	-		-	-	-	-
Dauphin (Dauphin)	-	-	-	-		0	0	-	-		1	0	-	-		0	0	-	-
Dauphin (Ochre)	-	-	-	-		0	0	-	-		2	1	-	-		0	0	-	-
	(n=3; 5)				(n=3; 5)				(n=2; 5)				(n=2; 5)						

supplement (Williamson 1988c). The data indicated that the 30-day 90% confidence interval was not exceeded at any beach during any sampling period, thus indicating acceptable quality for primary recreational activities. However, the 30-day 60% confidence interval was exceeded on a single occasion at Matlock beach during 1984. This occurrence was not observed during the subsequent summers of 1985, 1986 or 1987. The data also indicated that the 1-day 60% and 90% confidence intervals were usually exceeded on one occasion at each beach during each summer period. These exceedences occurred for brief periods of time. Fecal coliform densities were usually below the recreational water quality objective at the time of the next sampling interval.

Recreational water quality on the eastern shore of Lake Winnipeg was monitored during the bathing period at Victoria Beach, Hillside Beach, Lester Beach, east and west Grand Beach and Patricia Beach. The number of exceedences of the fecal coliform objective are located in Table 1. The data are similar to those observed at the west-side Lake Winnipeg beaches, except that the 30-day 60% and 90% confidence intervals were not exceeded during the period of record. Occasional exceedence of the 1-day 60% and 90% confidence intervals were observed at Victoria Beach, east and west Grand Beach and Patricia Beach. The fecal coliform densities were usually below the objective at the time of the next sample collection. These beaches were therefore of acceptable quality for primary recreational activities.

While the data indicated that the Lake Winnipeg beaches were not in exceedence of the 30-day fecal coliform recreational water quality objective, hence were of acceptable quality, the occasional elevated bacteria densities observed during individual sampling periods warranted additional investigation. These further preliminary investigations attempted to determine the source of the additional bacteria and to determine whether the occasional elevated densities could be predicted

from other related variables. Determining the source is important, since if human waste is implicated, the risk of transmitting disease vectors to bathers is greater than if the origin is wildlife or livestock. Further, should such elevated levels occur as a predictable response to other related variables, such as climatic conditions, additional studies could then be focused around such events.

The additional investigations conducted are discussed briefly below.

(1). Correlation of Field Observations and Climatic Information With Indicator Organism Densities.

The field observations recorded during each sampling trip were regressed with the respective indicator organism densities from selected beaches on both the east and west shores of Lake Winnipeg. Although a correlation was detected between water temperature and fecal coliform densities, it was thought that this was either spurious or only remotely associated with the causal factors. Bather load, while intuitively linked with temperature, was not correlated with increased fecal coliform densities. Relationships with other factors were not detected. Thus, factors such as recent rainfall, wind direction and others appeared not to play a direct role in the variation observed in the indicator organism densities.

(2). Investigation of Potential Point-Source Discharges Into Lake Winnipeg.

Point source discharges, such as drainage ditches that contained liquid during the monitoring program, were sampled. Several such drainage ditches, for example, were located along the western shore of Lake Winnipeg. Elevated fecal coliform densities were not observed that could account for the occasional exceedence of the 1-day mean fecal coliform objective.

The single largest point source discharge into the south basin of Lake Winnipeg is the Red River. It was hypothesized that large numbers of fecal coliform bacteria, contributed by the City of Winnipeg, could be occasionally reaching the Lake Winnipeg beaches. While this possibility was examined, the results were largely inconclusive. Several factors are involved and each were assessed.

Firstly, it was thought necessary that heterogeneous circulation patterns must exist within the south basin of Lake Winnipeg in order for the waters of the Red River to be moved within close proximity to the shorelines, rather than mixing completely upon entering the south basin. This was further considered to be a necessary factor since it did not appear reasonable to assume that small individual point-source discharges could similarly affect, albeit on different occasions, beaches along more than 60 km of shoreline. It was thought that some larger intermittent phenomenon was operative. Water circulation in large lakes is a complex phenomenon and can be affected by the velocity and direction of air movement, temperature as it affects water viscosity, gravitational influences, shoreline contour, location of influent and effluent streams plus others.

Computer enhanced satellite images (Landsat 4 with multi-spectral scanner) were examined to determine if such circulation patterns could be discerned. Although only two such images were examined, circulation patterns were evident. The south basin of Lake Winnipeg on May 17, 1981 was clearly circulating counter-clockwise, thus directing the waters of the Red River towards the eastern shoreline. On August 12, 1984, the gyre had reversed, and was circulating clockwise, thus directing the waters of the Red River towards the western shoreline. While these results are preliminary, they are important for determining that circulation patterns do exist within the south basin of Lake Winnipeg and that such currents are not stable.

Secondly, fecal coliform bacteria normally are inactivated relatively quickly within natural surface waters, largely due to the bacteriocidal properties of the ultra-violet portion of the light spectrum. Further multiplication is thought not to occur due to the requirements of fecal coliform bacteria for rather specific conditions that are unique to the intestines of homothermic animals. Die-off rates within natural waters have been examined extensively elsewhere and where found to follow first-order kinetics. Preliminary die-off rates were modelled using the following equation (Zison *et al.* 1978; Brown and Barnwell 1987):

$$C_t = C_0 e^{-kt},$$

where C_0 = initial fecal coliform density, organisms/100 mL,

C_t = fecal coliform density at time t , organisms/100 mL,

t = time in hours,

k = die-off rate constant/hour.

The die-off rate coefficient has been shown to vary with temperature, amount of organic matter and other factors and can range over several orders of magnitude. A coefficient was chosen (0.047/hour) that was derived from studies specific to the Red River within and downstream of the City of Winnipeg (MacLaren Engineers 1986). This value was similar to the median rate of 0.04/hour derived from studies conducted on fifteen streams in the United States (Zison *et al.* 1978). Fecal coliform data, collected during this period from the Red River at Selkirk, were assessed to determine if sufficient populations could theoretically survive in order to yield the observed densities. Ultimate populations were predicted following travel times of 12, 24, 36, 48 and 96 hours between Selkirk and the Lake Winnipeg beaches. Since the actual travel time is not known and is not easily determined, it is therefore not known

whether such travel times are realistic. Further, while only a single die-off rate was used for this exercise, the actual die-off rate probably varies considerably, even on a daily basis, due to temperature fluctuations and more importantly, variations in light intensity. Although highly speculative, it was determined that with a travel time of 96 hours and using the highest fecal coliform density observed in 1986 at Selkirk, sufficient densities could still survive to yield exceedences of the 1-day mean objective. However, during the monitoring program conducted in 1987, fecal coliform data collected from the Red River at Selkirk were consistently less than approximately 400 organisms/100 mL from the last week of June through to the middle of August. Application of the same travel times and die-off rate coefficient to these data indicated that very few fecal coliform bacteria would survive in order to be enumerated at any of the Lake Winnipeg beaches if carried by water circulation phenomena. However, occasional exceedences of the 1-day mean objective were observed on single occasions at a number of beaches during this period of time. Hence, while the Red River may theoretically provide a source of the occasional elevated fecal coliform densities observed at Lake Winnipeg beaches, the field data does not fully support this hypothesis.

(3). Investigation of the Contribution From Insect Exuvia and Bottom Sediments.

During 1987, several samples of bottom sediments and insect exuvia (pupal exoskeletons shed by emerging Ephemeroptera or mayflies) were analyzed for fecal coliform densities. Such substrates could protect fecal coliform bacteria from the normal bacteriocidal properties of ultra-violet light, hence increase their survival time. It was hypothesized that should bottom sediments contain a large density of fecal coliform bacteria, such bacteria could be routinely introduced into the water column following the re-mobilization of sediments by wind action. Further, large

numbers of mayflies emerge each summer and their exoskeletons accumulate along the shorelines. Similarly, should the exoskeletons support large densities of fecal coliform bacteria, such bacteria could then be re-introduced into the water column. The data indicated that bottom sediment and insect exuvia samples contained approximately 60 and 200 fecal coliform bacteria/g, respectively. Speciation analyses determined that all colonies were *E. coli*. This data indicated that while fecal coliform bacteria are present on bottom sediments and insect exuvia, measured densities are not sufficient to account for the occasional exceedences of the 1-day fecal coliform objectives.

(4). Estimating the Additional Risk to Bathers due to Exceedences of the 1-Day Mean Fecal Coliform Objective.

It is important to relate the potential additional risk to bathers of contracting gastroenteritis following exposure to exceedences of the 1-day fecal coliform objective in relation to the apparently accepted risk during other swimming periods. This can be determined by substitution into the regression equation calculated by Dufour (1983) and used by the U.S. EPA (1986) and Williamson (1988b) to recommend primary recreational water quality objectives for fecal coliform bacteria. This equation is as follows:

$$\text{Rate} = -11.74 + 9.40 (\log_{10} \text{geometric mean } E. coli \text{ density}/100 \text{ mL}),$$

where the rate is per 1000 bathers.

Hence, with fecal coliform densities at the recreational objective of 200 organisms/100 mL, approximately 9.9 persons out of every 1000 bathers would be expected to contract gastroenteritis. This estimated risk can range to 17.32 persons per 1000 bathers potentially contracting gastroenteritis while bathing in water containing the highest recorded daily mean of 1235 fecal coliform organisms/100 mL. However, this extrapolation is well beyond the data range used in the development of the mathematical equation and thus may not be valid. Most exceedences of the 1-day mean fecal coliform objective were much less than 1235 organisms/100 mL. While the acceptability of risk varies between individuals, this additional risk is thought to not be unacceptable. This is because the exceedences occurred only for a short period of time with fecal coliform densities usually in compliance with the objective during the next sampling period and because of the uncertainty associated with the mathematical estimation of the risk for both short-term and extended periods of exceedence. These combined factors are thought to have contributed to the apparent lack of reported gastroenteritis cases associated with bathing within such areas. However, it is important to note that it is extremely difficult to actually associate increases in gastroenteritis within the bathing population with fecal coliform densities. Nevertheless, future assessments should also utilize the information generated from the sample means collected on individual days in order to respond in a timely fashion to potentially more serious longer-term exceedences.

Whiteshell Provincial Park Beaches

Beaches located on Falcon, Star, West Hawk, Caddy, Brereton, Jessica, Big Whiteshell, Red Rock, White, Betula, Nutimik and Dorothy lakes were monitored during the study period. Table 1 contains a list of the exceedences of the 60% and 90% confidence intervals for the 1-day and 30-day mean fecal coliform objective. The

quality of all beaches was excellent with only one observed exceedence of the 60% confidence interval for the 1-day mean fecal coliform objective. This was recorded at Red Rock Lake during 1987. Fecal coliform densities were reduced on the next sampling occasion.

Central, Western and Southern Beaches

Beaches located on Gull, Pelican, Lake of the Prairies, East Blue, Childs, and Dauphin lakes were monitored for fecal coliform bacterial densities during the study duration. A summary of exceedences of the 60% and 90% confidence intervals for the 1-day and 30-day fecal coliform objective is contained in Table 1. Too few samples were collected from beaches other than those located on Gull Lake to permit valid comparison with the 30-day fecal coliform objective. Exceedences of the 1-day objective were observed only from beaches located on Lake Dauphin during 1986. The 60% confidence interval was exceeded on one occasion at Dauphin Beach and two occasions at Rainbow and Ochre beaches. Comparison of the observed data with the 90% confidence interval identified only one exceedence at Ochre Beach. Exceedences were not observed during 1985 or 1987 at Lake Dauphin beaches. The recreational water quality at the other beaches monitored were excellent. It is thought that the exceedences of the 1-day mean fecal coliform objective at the Lake Dauphin beaches did not represent an unacceptable risk to bathers during the summer of 1986, for similar reasons as discussed above with regard to Lake Winnipeg beaches.

Conclusions

Thirty-five beaches were monitored for recreational water quality purposes during the years 1984 to 1987. Fourteen of these beaches were monitored each year, the remaining were monitored during one or more years within this study period. The primary focus was to assess whether or not the primary recreational water quality objective for fecal coliform bacteria was being exceeded. Additional information was also acquired throughout the investigation. Information, although in some cases limited to select beaches, was generated on the presence of fecal streptococci, *Escherichia coli*, *Pseudomonas aeruginosa* and *Staphylococcus aureus*. Speciation studies were undertaken to determine the organisms enumerated in the fecal coliform and fecal streptococci analyses. Bacterial content of Lake Winnipeg bottom sediments and insect exuvia remaining from the emergence of mayfly nymphs were determined. The role of the point-source discharges into Lake Winnipeg, most important of these being the Red River, was examined to the extent possible.

It was determined that all beaches monitored, with the exception of Matlock beach on one occasion during 1984, were in compliance with the Manitoba 30-day mean fecal coliform objective for primary recreational water quality. However, most beaches located on Lake Winnipeg exceeded Manitoba's 1-day fecal coliform objective on one occasion during each of the four bathing seasons assessed. Extensive follow-up investigations indicated that such exceedences occurred at apparently random intervals and could not readily be associated with other variables such as bather load, precipitation, wind direction or point-source contributions of fecal coliform bacteria. It was thought that the additional risk to bathers associated with such exceedences was not unacceptable. Therefore, regulatory action was not necessary.

The recreational quality of beaches located within the Whiteshell Provincial Park were excellent throughout the duration of the study. A single exceedence of the 1-day fecal coliform objective was observed at Red Rock Lake during the summer of 1987.

Several exceedences of the 1-day fecal coliform objective were observed on Lake Dauphin beaches during the summer of 1986. Such occasional exceedences were not thought to represent an additional unacceptable risk to bathers. Similar exceedences at the Dauphin Lake beaches were not observed during 1987. Other beaches monitored in the central, western and southern regions of Manitoba did not exceed the fecal coliform objective.

The data sufficiently characterized the long-term variability of numerous beaches located in the most heavily populated regions of Manitoba. Further monitoring of this nature is therefore not required in the near future unless to address specific concerns or problems as evidenced by new medical information, alterations in major land-use practices surrounding specific recreational areas, or new point-source discharges occurring into specific recreational areas.

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